Gender Related Differences in Scaling Structure of Heart-Rate and Blood-Pressure Variability as Assessed by Detrended Fluctuation Analysis

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Abstract

Women, which have lower risks of cardiovascular events, are characterized by higher heart rate entropy. Aim of this study is to evaluate whether also the fractal structure of heart rate and blood pressure, as quantified by DFA, differs between men and women.

In 33 male and 23 female volunteers, we recorded R-R intervals (RRI) and systolic (S) and diastolic (D) blood pressure (BP) for 10' in 3 conditions: supine rest, sitting at rest and sitting during exercise. We calculated a spectrum of scale exponent α(t) as function of the time scale t*, by DFA. We also calculated traditional spectral indexes for assessing cardiac and vascular autonomic tone. We found gender related differences in α(t) only during supine rest. Women had significantly lower α(t) of RRI at scales <6 s, and higher α(t) of BP at the longer scales, the difference being significant for DBP at t>60s. Results may in part be explained by gender differences in cardiac autonomic tone at rest.*

1. Introduction

Detrended Fluctuation Analysis, DFA, is a popular method for assessing the self-similarity of time series [1]. DFA is based on splitting the time series into boxes of *n* consecutive data, and in the calculation of a variability function, *F*, over these boxes. The function *F* depends on the block size *n*. For pure monofractal signals it is proportional to a power α of *n*: $F(n)=k\times n^{\alpha}$. The exponent α is related to the Hurst coefficient *H*: in particular, α is equal to *H* for fractional gaussian noises, and to *H+1* for fractional Brownian motions. Thus, DFA provides a simple method for estimating the Hurst exponent of a pure monofractal time series, because α can be calculated as the slope of the regression line between *F(n)* and *n* plotted in a log-log scale.

DFA is widely employed in heart rate variability (HRV) studies. However, since its first applications, it appeared clear that the heart rate is better described by two exponents [2]: a short-term and a long-term scale exponent often called α_1 and α_2. Actually, most of the DFA studies of heart rate estimate α_1 over scales $n<12$ beats, and α_2 over larger *n*.

More recently, however, our and other groups suggested that the two-coefficient model largely oversimplifies a more complex phenomenon [3,4]. These authors proposed alternative DFA-based methods in order to derive a continuous spectrum of scale exponents $\alpha(n)$, function of the beat scale *n*, from *F(n)*. In particular, they showed that $\alpha(n)$ describes the effects of ageing [3] or high-altitude hypoxia [5] on HRV better than α_1 and α_2 alone; and that $\alpha(n)$ characterizes HRV alterations associated to congestive heart failure better than the two-coefficient model [6]. These results are coherent with the hypothesis that the heart rate has a multifractal nature [7].

Women have lower risks of cardiovascular events than men. They are also characterized by different spectral indexes of HRV [8], and by higher HRV entropy [9]. Aim of the present study is to verify whether also the fractal structures of heart rate and blood pressure differ between males and females. This may help to better understand differences between sexes in cardiovascular regulation, and to evaluate whether gender represents a confounder in self-similarity studies. Following the more recent approaches, this is done by calculating a spectrum of DFA scale exponents. Traditional spectral indexes are also assessed for comparison.

2. Methods

We enrolled 33 male and 23 female healthy volunteers matched by age (males: 34.6 ±9.3 yrs.; females: 34.5 ±10 yrs., M ±SD), with similar values of systolic (123 ±7 vs. 119 ±21 mmHg) and diastolic (73 ±13 vs. 66 ±18 mmHg) blood pressure measured at rest in sitting position.

ECG and finger arterial pressure (Finometer, FMS, Amsterdam, The Netherlands) were simultaneously recorded for 10 minutes in each of the following conditions: supine at rest (Supine); sitting at rest (Sitting); and sitting while performing a light exercise with an arm-cycloergometer (Exercise). We selected these three conditions because characterized by a progressive activation of the sympathetic tone and by a progressive decrease of vagal tone. Beat-by-beat values of R-R

intervals (RRI) and systolic (SBP) and diastolic blood pressure (DBP) were extracted from ECG and from arterial pressure.

DFA was applied to RRI, SBP and DBP series to calculate a continuous spectrum of scale exponents $\alpha(n)$ as the derivative of $F(n)$ vs. n in a log-log plot (see details in [3]). In this study, however, we compared two groups, males vs. females, which are expected to be characterized by different mean heart rate. In fact, literature reports higher heart rates in women than in men (e.g., see [10]). If the mean heart rate differs between groups, when we compare α values estimated at the same number of beats n we are actually comparing different time-scales t. To avoid this problem, α values were expressed as function of time rather than number of beats. This was done by substituting the beat-index n with the time variable t_n defined as: $t_n = n \times \langle RRI \rangle$, where $\langle RRI \rangle$ is the mean RRI. Then, $\alpha(t_n)$ values where interpolated over time to obtain a continuous function $\alpha(t)$.

Traditional spectral analysis was performed to calculate the high frequency (HF) and low frequency (LF) powers and the LF/HF powers ratio of RRI; HF and LF/HF are markers of cardiac vagal tone and cardiac sympato/vagal balance [11]. The low-frequency power of DBP (LF_{DBP}) was also computed as index of vascular sympathetic tone [12].

Mean values of RRI, SBP and DBP and log-transformed spectral indexes were compared by repeated measures ANOVA with "manoeuvre" as the factor "within", and gender as the factor "between". Differences between males and females in $\alpha(t)$ were assessed by considering a sub-set of 25 time instants t_i evenly sampled over log t; statistical significance of the differences between males and females was assessed at each t_i by unpaired t-test.

3. Results

Mean values of SBP, DBP and RRI are shown in Table 1. "Manoeuvre" and "gender" were significant factors for RRI. In fact, RRI decreased with the manoeuvre and was lower in females. As to blood pressure, only "manoeuvre" was significant, both SBP and DBP increasing similarly in males and females from supine to sitting at rest, and from sitting at rest to sitting during exercise.

The scale exponents $\alpha(t)$ are shown in figure 1. In supine position at rest, $\alpha(t)$ of RRI decreased with t up to a minimum between 10 and 20 s; then, at larger t, it increased reaching a "plateau". However, at t shorter than the position of the minimum, $\alpha(t)$ was higher in men than in women, the difference reaching the statistical significance at t<6s. Change of posture and exercise modified $\alpha(t)$ as described previously [3]. Moreover, gender differences at shorter scales largely decreased in sitting position, and disappeared completely with exercise. During supine rest, $\alpha(t)$ of blood pressure was lower in males than in females at the larger scales, the difference being statistically significant for DBP at t>60 s. Also in this case gender differences decreased in sitting position, and disappeared with exercise.

Table 1. Mean (SD) of SBP, DBP and RRI in males, M, and females, F; * indicates a significant difference (p<5%) between groups.

	Supine		Sitting		Exercise	
	M	F	M	F	M	F
RRI ms	984 (23)	876* (28)	873 (20)	794 (25)	757 (17)	688 (18)
SBP mmHg	118 (2)	114 (4)	123 (3)	119 (4)	140 (3)	132 (4)
DBP mmHg	67 (2)	61 (3)	73 (2)	66 (4)	80 (2)	74 (3)

Spectral indexes are reported in table 2. The factor "manoeuvre" was significant: HF decreased while LF/HF and LF_{DBP} increased from supine to sitting and to exercise. "Gender" was significant for LF/HF only: in particular, during supine rest the ratio between power spectra was significantly greater in males than in females.

Table 2. Mean (SD) of spectral indices in males, M, and females, F; * as in table 1.

	Supine		Sitting		Exercise	
	M	F	M	F	M	F
HF ms^2	2.6 (0.1)	2.6 (0.1)	2.4 (0.1)	2.4 (0.1)	2.2 (0.1)	2.0 (0.1)
LF/HF %	28 (5)	6 * (7)	55 (4)	41 (6)	63 (4)	57 (5)
LF_{DBP} $mmHg^2$	0.39 (.04)	0.32 (.07)	0.71 (.05)	0.73 (.07)	0.78 (.03)	0.77 (.06)

4. Discussion

Our study demonstrated for the first time gender related differences in the fractal structure of heart rate and blood pressure as assessed by DFA. We compared age-matched groups of normotensive volunteers, thus excluding confounders like hypertension or ageing. We found significant differences during supine rest only, when the vagal tone is highest and the sympathetic tone is lowest. This strongly suggests a role of the autonomic outflow in determining differences due to gender.

It has been observed that the DFA exponents of RRI at the shorter scales increase with the sympatho-vagal balance [3]. Our results therefore may be explained

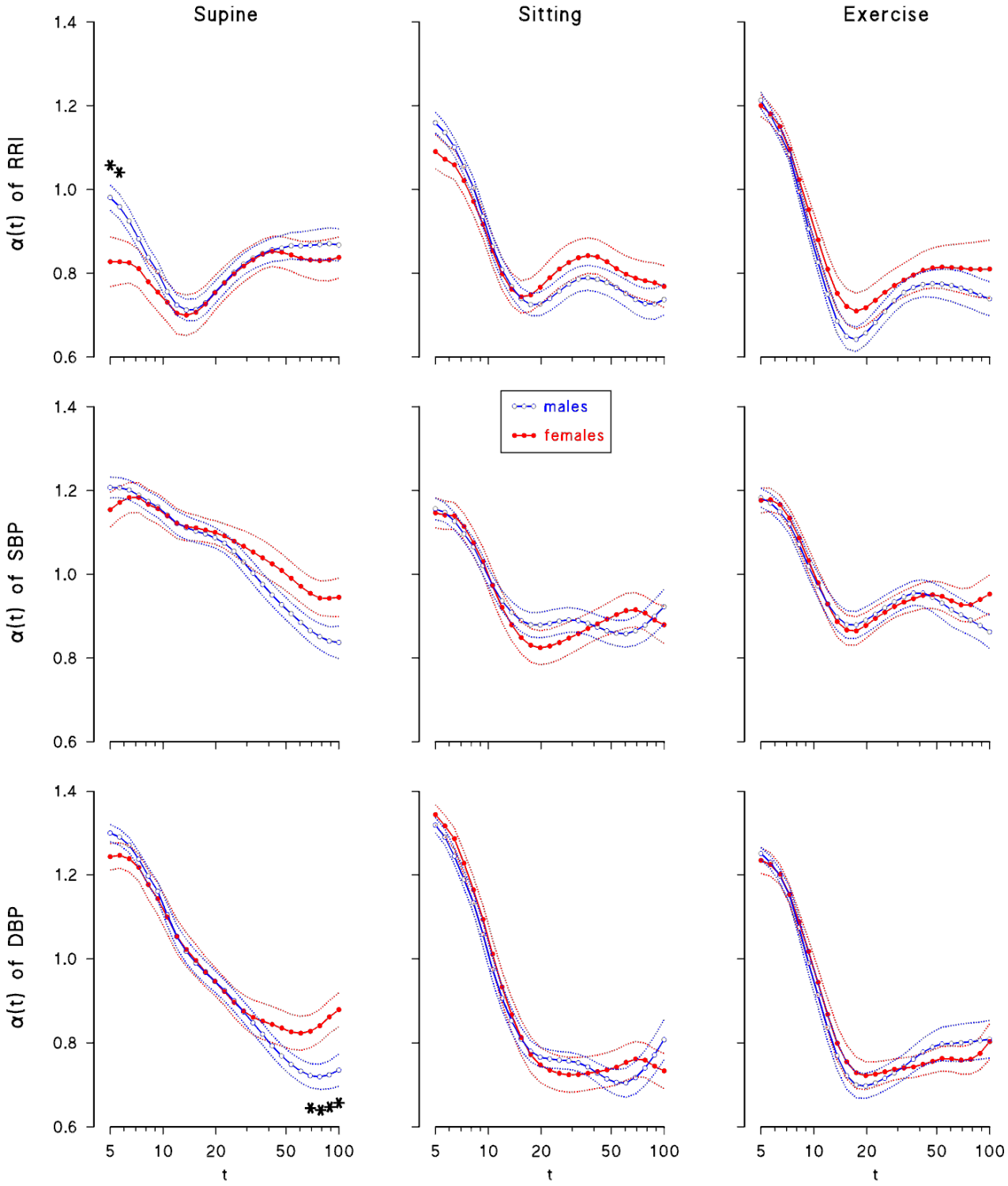

Figure 1. Scale-exponent functions, $\alpha(t)$, calculated for RRI, SBP and DBP in males (open circle, blue) and females (solid circle, red) during supine rest, sitting at rest, and performing a light physical exercise while sitting; the * indicate significant differences between males and females at $p<0.05$.

making the hypothesis that the cardiac sympatho-vagal balance in supine rest is higher in men than in women. Spectral analysis confirms this hypothesis. The significantly higher LF/HF ratio in men (table 2) actually indicates a higher cardiac sympatho/vagal balance in males than in females. Interestingly, gender differences in the LF/HF ratio appear in the supine condition only. Since the HF power, index of vagal tone, is the same in men and women in all conditions, supine rest included, we might conclude that, in the condition of lowest sympathetic activity, differences in $\alpha(t)$ of RRI at short scales are due to a residual cardiac sympathetic outflow higher in males than in females.

An explanation of gender differences in scale exponents of blood pressure appears more difficult. As for DFA coefficients of RRI, differences regard the supine condition only. However, these differences do not seem related to the autonomic regulation. Actually, the vascular sympathetic tone, quantified by LF_{DBP}, increases with the change of posture from supine to sitting (table 2), but it does not show differences between males and females. It is possible that a different cardiovascular response to lying (presumably reflecting differences in the strategy to counteract blood centralization occurring in clinostatic condition) plays a role in the genesis of gender related differences in the fractal structure of blood pressure in supine subjects.

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